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Research paper

The impact of renewable energy consumption and environmental sustainability on economic growth in Africa

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ABSTRACT

In line with the global call for alternative sources of energy rather than conventional fossil-based sources, research in the area of renewable energy, energy efficiency, and sustainability seems to have intensified in Africa in the last five years. As a form of a contribution to the existing body of knowledge, this study seeks to parametrically estimate the effects of renewable energy consumption and environmental sustainability on economic growth in Africa. Using panel data, for thirty-seven African countries, and employing the system Generalized Method of Moments estimation technique which more efficiently solves the problems of endogeneity and omitted variable bias than least squares and causal estimation method, this study found that renewable energy adoption and development will lead to an increase in economic growth in Africa, both in the long run and short run as a one percent increase in renewable energy consumption will lead to 0.07% and 1.9% increases in economic growth in both the short-run and long-run, respectively. The study also found that environmental sustainability through a reduction of emission may not be Africa's priority towards achieving an all-inclusive development at present because the coefficient of CO2 emission in the study is not statistically significant. Therefore, African countries' governments should intensify efforts towards developing the renewable energy sector, especially using policy instruments, while also harnessing the already mature nonrenewable industry for more rapid growth in the continent and the attainment of Agenda 2063.

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1. Introduction

There has been a global call for renewable energy consumption in all countries of the world for the last two decades, especially the most energy-consuming ones found in Asia, the EU, and the Americas, as a way of promoting environmental sustainability (Nguyen and Kakinaka, 2019; Brodny and Tutak, 2020). The projections about the depletion of fossil fuels globally and the new quest to move to greener energy consumption provide the impetus for actions to mitigate the harmful effects on the climate (Maji et al., 2019). Non-renewable energy consumption has been argued to have more negative effects on the environment than positive effects, and some of those negative impacts include CO2 emission and other forms of environmental degradation. These are in sharp contrast to the tenets of environmental sustainability (Jamel and Derbali, 2016).

Many energy scholars (Nathaniel and Iheonu, 2019) have researched the effects of CO2 emission as a measure of environmental sustainability and how it ultimately influences economic growth. For instance, Armeanu et al. (2017) believe that Africa's long use of conventional exhaustible energy resources has raised serious environmental concerns while hampering sustainable economic growth. They also noted that continuous dependence on fossil fuels to meet an upward energy demand will only increase the degradation of the environment without still meeting up with the increasing energy needs of Africa and Asia (Said and Hammami, 2015). More specifically, Nathaniel and Iheonu (2019) argued that the continuous nonrenewable energy consumption in the continent will persistently and significantly increase CO2 emission in the continent and could affect long-run economic growth. Another stream of research in the energy discourse commonly focuses only on the relationship between renewable energy consumption and economic growth, either in the long-run or short-run (Antonakakis et al., 2015). For instance, Bhattacharya et al. (2016) found that renewable energy consumption has a positive and significant effect on economic growth in the long run

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while [Alper and Oguz \(2016\)](#) arrived at an identical outcome with a short-run focus. Their arguments omit the CO₂ consideration and emphasize how renewable energy consumption will increase renewable energy production, enhance productivity and increase gross domestic product. Thus, there seems to be independent within the extant literature in the analysis of CO₂ as a measure of environmental sustainability and renewable energy consumption, and how each of them impacts economic growth in Africa

Consequently, little work has examined the joint effects of CO₂ emissions and renewable energy consumption on economic growth in Africa, especially, whether the inclusion of the former in the economic performance equation could alter the expected relationship between renewable energy consumption and economic growth in the continent. Also, few studies have investigated the role of important factors such as the availability of electricity and labor force as control variables in understanding how renewable energy consumption and environmental sustainability impact the economic growth in Africa. Not least, these existing studies have mostly focused on European and Asian developing countries ([Bildirici and Özaksoy, 2018](#)), with few focusing on the African scenario. Most African countries are still at crossroads regarding the best policies that can ensure a sustainable future for the economy. Many African countries still hugely depend on non-renewable energy and the recent inclusion of renewable energy in the supply mix seems not to be reducing the emissions ([Le et al., 2020](#)). Therefore, ensuring an appropriate understanding of the nature of the relationship between renewable energy consumption, environmental sustainability, and economic growth requires the inclusion of various local factors in the study of these relationships.

The key objectives of this study, therefore, are to (i) assess the relationship between renewable energy consumption and economic growth in Africa (ii) analyze the relationship between environmental sustainability and economic growth in Africa, and (iii) investigate the moderating role of environmental sustainability on the nexus between renewable energy consumption and economic growth in Africa. This study intends to include several control variables including access to electricity ([Dogan et al., 2016](#)), gross fixed capital formation and labor force participation ([Singh et al., 2019](#)). To achieve these objectives, the study will address the research questions: (i) how do renewable energy consumption and economic growth relate in Africa in both the short-run and the long-run?, (ii) what is the nature of the relationship between environmental sustainability and economic growth in Africa?, and (iii) to what extent do environmental sustainability serve as a moderating factor on the nexus between renewable energy consumption and economic growth in Africa?

The novelty of this study lies in (i) its systematic and joint examination of renewable energy consumption, environmental sustainability, and economic growth within the African context, for which extant literature appear to be mostly focusing on the detached components and generally scant (ii) it compares the short-run effects of renewable energy consumption in the continent to the long-run impacts; an improvement to most of the existing studies that are either focusing on the short-run or the long-run (iii) the study incorporates some African countries that have received little attention in energy research, probably due to the inadequacy of data or intellectual oversight, and (iv) the situation of the study within the context of long-run sustainability of the region and beyond, more specifically as the findings may help in shaping renewable energy and sustainability policies in Africa going forward, as well as contribute solutions for the attainment of the United Nations Sustainable Development Goals (SDGs) and the Agenda 2063 of the African Union. This study also adopts the Generalized Method of Moments (GMM) panel data estimation techniques because of its efficacy in controlling for

the endogeneity of the lagged dependent variable in a dynamic panel data model, omitted variable bias, unobserved panel heterogeneity, and measurement errors in research data ([Maji et al., 2019](#)).

2. Literature review

2.1. Theoretical premise

2.1.1. Renewable energy consumption and economic growth

The linkage that economic growth has with renewable energy consumption and other energy variables such as electricity consumption, nuclear energy utilization, total energy use, and electricity consumption, has been harmonized by studies such as [Omri et al. \(2019\)](#), [Aspergis and Payne \(2009\)](#), [Chen et al. \(2007\)](#) and [Ozturk \(2010\)](#) into four testable hypotheses; growth hypothesis, conservation hypothesis, feedback hypothesis, and neutrality hypothesis.

According to the growth hypothesis, a unidirectional causality exists between renewable energy consumption and economic growth, running from the former. This further implies that energy consumption is very pivotal to the growth and progress of any economy. This huge influence could be directly on the productive factors and core sectors of the economy or indirectly through human wellbeing and improved living standards. Thus, this study could infer and support ([Aspergis and Payne, 2009](#)) that major shocks on the energy sector could affect the economy negatively. One criticism of this hypothesis lies in its failure to highlight the dynamics of renewable energy consumption. For instance, biomass energy is renewable but its excessive consumption may sometimes lead to massive environmental pollution which takes a negative toll on the economy, ultimately.

The conservation hypothesis takes an opposite stance from the growth hypothesis. It posits that a unidirectional causality exists running from economic growth to energy consumption. This further means that when there is an increase in the overall economic activities and value of total goods and services, people have more access to energy, just as has been witnessed in the United States in the last two decades ([Mohammadi and Ram, 2017](#)). On the other hand, it also implies that for a nascent economy (such as Nigeria or Ghana) hindered by the lack of infrastructure and mismanagement of public resources, there could be gross inefficiencies leading to a decline in the overall economic activities, and subsequently, in the demand for goods and services, including energy consumption ([Squalli, 2007](#)).

As the name suggests, the feedback hypothesis posits that some sort of a feedback loop-like causal relationship exists between energy consumption and economic growth. Thus, while, it highlights that increased energy consumption could spur up economic activities for the better, it also emphasizes that an increase in economic growth will increase people's economic power. This will further enable them to consume more energy. [Squalli \(2007\)](#) refers to it as a complementary and bidirectional causality between the two.

Finally, the neutrality hypothesis suggests that there is no causal relationship between economic growth and energy consumption. It views energy consumption as a micro aspect of the overall economic growth, and hence, cannot cause a major change in economic growth. The hypothesis further emphasizes that government policies aimed at expanding or restricting energy consumption also have no effects on economic growth. There may be exceptions to this hypothesis, however. For instance, for an economy like Nigeria that depends on both local and international energy consumption to thrive, it would suffice to posit a counterargument regarding this hypothesis, thus falling back to the growth hypothesis.

2.1.2. Economic growth and environmental sustainability

To highlight the theoretical underpinning of the relationship between economic growth and environmental sustainability, the revised neoclassical theory of environmental sustainability is discussed in this sub-section. This theory was popularized in the individual works of Boulding (1966) and Dragulanescu and Dragulanescu (2013). The theory posits that the economic system is a complex web comprising of two distinct economies; (1) the real economy — the part of the economic system made up of economic activities and value creation, as well as the effective allocation and distribution of scarce resources; and (2) the extended economy — which supports life on earth: the part of the economic system that recognizes the interdependence between the economy and the environment. They further added that the real economy is an open and circular subsystem that can only function effectively with the support of its ecological foundation — the environment. There is, therefore, the need to maintain a balance between the two economies to ensure the sustainability of both the economic and environmental resources. The theory is summarized in Fig. 1, referred to as a material balance model.

2.2. Empirical evidence

2.2.1. Evidence on renewable energy consumption in Africa

A study by Harrison and Adams (2017) reveals that poorer African households seem to spend a more sizable share of their total expenses on energy than their wealthier counterparts. The World Bank has launched the Sustainable Energy for All Initiative, aimed at achieving universal energy access, accelerating improvements in energy efficiency, and remarkably increasing the share of renewable energy to Africa's energy mix especially by 2030. There also seems to be a strong inter-relationship between economic growth and energy consumption in Sub-Saharan Africa, according to Kahsai et al. (2012). This highlights the need for sustainable development policies which are focused on the efficient allocation of resources to improve the chances of increased energy access, mostly from renewables, in the region. This outcome is equally true for Europe, as reported by Ntamos et al. (2018) in their study of 25 European countries. Though an important contribution to the body of knowledge, their studies failed to investigate the interrelationship between renewable energy consumption, distinct from the total final energy consumption, and economic growth. Even though Kahsai et al. (2012) advocated for sustainable policies that can promote efficient allocation of resources and improved energy access, they were silent on the same policies that can equally focus on how resource allocation can impact the environment. This is pertinent, as efficiency in resource allocation may probably be measured by the number of recipients and not necessarily by the environmental sustainability issues that the allocation prevents. By bringing the sustainability component in the study of renewable energy access and consumption, this study would contribute to filling this gap.

Neuhaus (2016) sought to examine the nature of the relationship existing between renewable energy consumption and economic growth in a panel of Sub-Saharan African countries within a time scope of 1990 to 2011. The results indicated a long-run and statistically significant relationship between real GDP and renewable energy consumption. He further found a unidirectional causal relationship running from GDP to renewable energy in Africa, especially in the long run. He, therefore, recommended that the government should help in stabilizing institutions that will enable Africa to fully exploit renewable energy options for a better Africa, both at the moment and in the future. Their study highlights the importance of a strong institutional framework in ensuring that renewable energy utilization is in alignment with the environmental sustainability targets set by the United

Nations and the African Union through the sustainable development goals and the Agenda 2063. This study extends this view further by quantifying how these sustainability considerations can affect the Saharan African economy. Ergun et al. (2019) also investigated the nexus between renewable energy consumption and social and economic variables, for a panel of 21 African countries for the period 1990 to 2013. After they estimate a random-effects generalized least squares regression, they found that African countries with the highest Human Development Index and GDP per capita have a lower share of renewable energy in the national grid. This may imply that the growth path of most African countries does not include significant renewable energy consumption, probably, because of a lack of knowledge of its potential impacts on the overall economy. Thus, this study adds some clarity to this discourse. They also found that there is a positive relationship between renewable energy integration and foreign direct investment. They finally highlighted the policy implications of the findings in the light of a review of the energy mix of selected African countries.

From the foregoing, many studies have established a positive relationship between renewable energy and economic growth in Africa, however, there is also a point of departure from those popular findings within the extant literature. Maji et al. (2019) focused on renewable energy and economic growth in West Africa. They adopted a panel dynamic ordinary least squares (DOLS) estimation technique for a sample of 15 West African countries within a time scope of 1995 and 2014. Their results indicated that renewable energy consumption reduces the rate of economic growth in these countries. This, according to their study, stems from their belief that the major renewable energy source in West Africa is biomass, which is polluting and highly unclean and hence, may not be fully supportive of environmental sustainability. This is also in line with the findings of Ahmed and Shimada (2019) who posit that economic growth depends on non-renewable energy consumption in Latin America and the Caribbean countries and not renewable energy consumption.

Most empirical studies conducted for either the European countries or OECD support a linkage between renewable energy consumption and economic growth or environmental sustainability and found convincing evidence to suggest that renewable energy consumption supports economic growth while ensuring environmental sustainability (Marinaş et al., 2018; Lee, 2019). For instance, Lee (2019) found enough evidence to suggest the existence of a relationship between renewable energy consumption, CO₂ emissions, economic growth, and industrialization in the long-run and short-run in Europe. The study further noted that while renewable energy consumption has been increasing with growing evidence, CO₂ emissions have been declining in the region. The result finally suggested that the attainment of economic growth and industrialization has negative environmental implications and that the increased renewable energy consumption may play an important role in curbing carbon emissions and crowding out these negative implications. However, the magnitude of the role played by renewable energy adoption in curbing negative environmental implications largely depends on both the type of renewable energy deployed and the total share of renewable energy in the energy mix. In the case of many African countries that are beginning to adopt renewables but are still heavily reliant on fossil fuels, like Nigeria, the environmental implications caused by carbon emissions could still be compounding.

Sawin et al. (2016) identified three key drivers of renewable energy policies in Africa: environmental drivers, economic drivers, and political and security drivers, but failed to thoroughly examine the success of these renewable energy policies in increasing renewable energy consumption. Nyiwul (2018) also opines that domestic income is a strong driver of sustainable energy consumption in Africa.

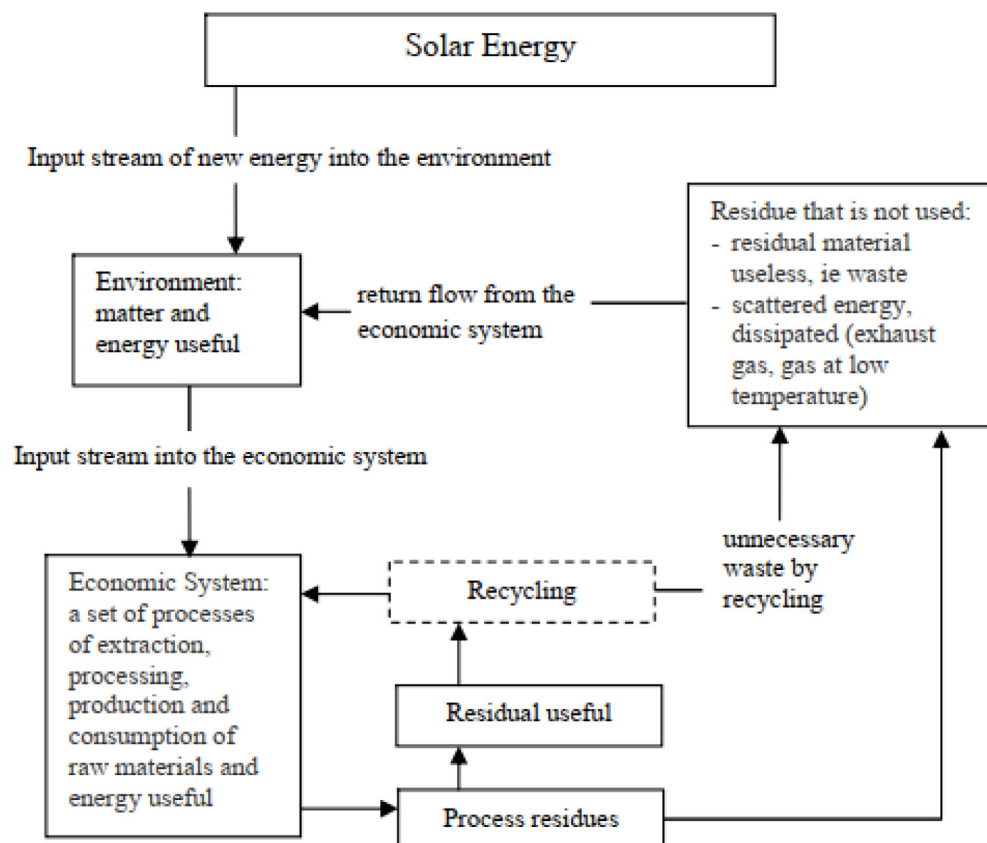


Fig. 1. Material balance model.

Source: Dragulanescu and Dragulanescu (2013).

Not least, some other researchers have argued that the linkage between renewable energy consumption and economic growth could be best described as neutral, noting that there seems to be no evidence that renewable energy has a significant impact on growth (Inglesi-Lotz, 2016; Dogan et al., 2016; Bozkurt and Destek, 2015; Ocal and Aslan, 2013).

2.2.2. Evidence on environmental sustainability in Africa

Development in Africa has varying results for the different countries making up the region and this may be attributed, among other things, to the economic priorities of the respective countries of the countries. While some countries have made tremendous progress in the areas of social, economic, and environmental sustainability, others are still struggling (UNECA, 2014). There is also a strong linkage between the level of environmental sustainability and the extent a country has gone in promoting a green economy, and by this premise, Ethiopia is one of the few African countries that already have a clear-cut green economy strategy in place. The most promising green economy markets tend to be those related to renewable energies, agriculture such as bio trade, and sustainable tourism (Chukwu, 2020).

The core dimensions of sustainability, according to Bartniczak and Raszkowski (2018) could be economic, environmental, social, institutional, spatial, and economic, and the world seems to be facing the most challenges in three dimensions: economic, social, and environmental (United Nations, 2013), even though the extent to which the world is facing each of them is ignored. ISPI (2016) posits that despite the slow and uneven progress towards democracy across the African continent, unrest, corruption, insurgencies, and civil wars still serve as threats to all aspects of environmental and social sustainability. Brouwer et al.

(2016) found that economic development is a core determinant of environmental sustainability. Hence, countries that place more emphasis on development notice a remarkable improvement in their environmental sustainability. He arrived at this result by investigating seventy-two developing countries in Africa and Asia for the time scope of 2006 to 2008. Similarly, Denny and Marquat-Pyatt (2018) found demographic attributes of a country to be a primary but nonexclusive force affecting environmental sustainability in Africa. They also opined that the efforts to improve environmental sustainability in African countries do not yield equal outcomes because of geographic and climatic differences between these countries. While environmental sustainability, as seen in the studies, is an end goal in itself, it is equally important to investigate how the attainment of environmental sustainability can benefit the aggregate economy.

The findings of Ahenkan and Osei-Kojo (2014) reveal that even though African governments may have implemented several policies towards sustainability, there seems to be a big doubt about whether Africa can achieve sustainable development, especially given the obvious lags in most countries in the areas of job creation, climate change mitigation and agricultural mechanization. By implementing renewable energy policies such as Feed-in-Tariffs and renewable energy businesses, African governments could encourage private sector stakeholders to invest in creating renewable energy jobs. This would possibly enhance the uptake of renewable energy in the economy while simultaneously increasing environmental sustainability and people's economic power, thus impacting economic growth positively. Samimi et al. (2011) estimated and evaluated the relationship between environmental sustainability index and economic growth in developing countries, mostly from Africa. Adopting a panel regression analytical technique for the period of 2001–2005, their findings contradict the normal Kuznets Curve, implying an inverted-U curve

regarding the relationship between environmental sustainability and economic growth.

By using carbon dioxide (CO₂) as a proxy for environmental sustainability (which also provides some justifications to our study), [Asongu \(2017\)](#) investigated the comparative persistence of environmental sustainability in 44 African countries within the time scope of 2000 to 2012. Adopting the Generalized Method of Moments (GMM), the study found that political instability leads to a higher persistence on the level of CO₂ emitted per capita. He also added that landlocked African countries tend to be more persistent in CO₂ per capita emission but not for the CO₂ emissions that emanate from liquid fuel consumption. [Asongu et al. \(2018\)](#) also analyzed how increasing ICT penetration in Africa can add to environmental sustainability by reducing CO₂ emissions. Their empirical evidence was based on the Generalized Method of Moments, with a sample of forty-four African countries and a period of 2000 to 2012. They found that ICT has no significant relationship with CO₂ emissions but increasing ICT could have a positive net impact on CO₂ emissions per capita while increasing mobile phone usage in these countries has a net negative impact on CO₂ emissions from liquid fuel consumption.

2.2.3. Evidence on economic growth in Africa

[Tugcu et al. \(2012\)](#) investigated the long-run and causal relationships between non-renewable energy consumption, renewable energy consumption, and economic growth in G7 countries for the period of 1980–2009. Using the Autoregressive Distributed Lag approach to cointegration and the Hatemi-J test for causality, they found that both nonrenewable and renewable energy consumption influence economic growth and hence could be adopted concurrently for more rapid growth. This is similar to the findings of [Aspergis and Danuletiu \(2014\)](#) which suggest a long-run positive causality running from renewable energy to real GDP and further provides strong evidence to show interdependence between renewable energy consumption and economic growth across selected African, American and European countries. [Eggoh et al. \(2011\)](#), and [Ahmed and Shimada \(2019\)](#) also found a significant long-run relationship between renewable energy consumption and economic growth, not just in Africa, but also in South Asia and other Asian countries. These studies seem to be lacking as they mostly focused on the long-run relationship between renewable energy consumption and economic growth, also failing to identify if renewable energy consumption affects environmental sustainability, and in turn, if environmental sustainability affects growth.

In his study of the effects of import and export components on economic growth in eighteen African countries within the time scope of 1996–2015 and using the panel fixed effects estimation technique, [Oyebanjo \(2017\)](#) found that both exports and imports have a statistically significant relationship with economic growth. Specifically, they highlighted that growth in raw material exports, and not manufactured exports, have a significant relationship with GDP growth while the growth in manufactured imports, and not raw materials imports, have a significant relationship with GDP growth. Their results also indicated that the export concentration index has an insignificant relationship with GDP growth. Furthermore, adopting a panel data model with country-specific fixed effects, [Moral-Benito \(2009\)](#) found that the key determinants of growth include the price of investment goods, distance to major world cities, and political rights. He believes that growth-promoting policy strategies should aim at tax reduction and the control of distortions that increase the prices of investment goods; promote democracy-encouraging institutional reforms and increase access to international markets.

The concept of sustainable economic development, which is usually likened to economic growth by some scholars, has three

key components which must balance for an equilibrium to exist: economic dimension, a social dimension, and environmental dimension ([Tutak et al., 2020](#)). They further argued that one of the industries that could play an important role in a country's quest for sustainable economic development (economic growth in our context) is the energy industry. Though there are contrasting views on the role of the industry, especially in terms of renewable and non-renewable energy, countries should consider their peculiarities in making their energy plans to ensure sustained growth and environmental protection.

On the other hand, physical capital formation, a vibrant export sector, and human capital formation have been identified also, as major influencers of economic growth among African countries, according to [Ndambiri et al. \(2012\)](#) in their panel data study of 19 African countries for the period of 1982–2000 using the Generalized Method of Moments (GMM) econometric technique. Domestic investment, education, net ODA inflows, urban population government effectiveness, and metal prices have also been found to have a positive and significant relationship with economic growth in Africa ([Anyanwu, 2014](#)).

3. Methods and materials

To address the research question this study used the dynamic Generalized Method of Moments (GMM) estimation technique of panel data analysis. The key steps in the methodology include data collection and model building and its validation. GMM is adjudged appropriate for this study as it overcomes endogeneity issues, peculiar to some previous studies ([Maji et al., 2019](#)), and also deals with issues of omitted variables, thus, making the parameter estimates to be more reliable.

3.1. Data and variables

The World Development Indicators (WDI) is one of the World Bank's first compilation of cross-country comparable data on development. The database is comprised of more than 1400 time series indicators for about 217 economies and more than 40 country groups, with data for many of the indicators going more than 50 years, i.e., mostly starting from 1960. The 2018 edition of the WDI, from where the variables of this study were drawn, contains a brief presentation of the major indicators, together with regional and topical highlights and maps. Also, the tables in the WDI 2018 include all the member countries of the World Bank (189) as well as all other economies with a population of 30,000 and above (217 total). There is an alphabetical arrangement of countries and economies (which made it easier to identify the important variables for the 37 African countries sampled for this study) except for Hong Kong, China, and Macao, China; two of which were placed after China.

This study, therefore, is a quantitative analysis of the core economic and energy variables — renewable energy consumption, environmental sustainability, and economic growth, which employs a panel of thirty-seven African countries from 2008 to 2014, obtained from the World Development Indicators (WDI) database of the World Bank ([WDI, 2018](#)). The key variables in this study include the Gross Domestic Product (GDP), renewable energy consumption (REC), CO₂ emission (CO₂) used as a proxy for environmental sustainability in line with ([Asongu, 2017](#); [Nathaniel and Iheonu, 2019](#)), gross fixed capital formation (GFC), Labor force (LABFORCE), and access to electricity (ACCELC). These variables are classified into the dependent variable (the natural logarithm of GDP), the endogenous variables (the one-year lag of GDP), the explanatory variables (REC and CO₂ emissions), and the control variables (GFC, LABFORCE, and ACCELC, which also serve as instruments for the system GMM estimation.

3.2. Models

This study adopts the Generalized Method of Moments (GMM) panel data estimation techniques because of its ability to control for endogeneity of the lagged dependent variable in a dynamic panel data model, omitted variable bias, unobserved panel heterogeneity, and measurement errors in research data. The instrumental variables described above are strictly exogenous as required for GMM estimation; the number of cross-sections N is 37 since the study focuses on 37 African countries while the period T is 7, i.e. 2008 to 2014, hence, also satisfying the condition for GMM adoption. The time scope of 2008 to 2014 was adopted because of the lack of data for the succeeding years for many of the countries under study.

To achieve the objectives of this study, two-panel data models are estimated. The functional form of the models is first presented:

$$\ln GDP_{i,t} = (\ln GDP_{i,t-1}, \ln GFC_{i,t}, REC_{i,t}, CO2_{i,t}, ACCEL_{i,t}, LABFORCE_{i,t}) \quad (1)$$

where $\ln GDP$ is the natural logarithm of the Gross Domestic Product; i is the number of cross-sections ($=1, \dots, N$); t is the number of time series ($=1, \dots, T$). All other variables remain as defined in Section 3.1. The core models are presented below:

$$\begin{aligned} \ln GDP_{i,t} = & \alpha_1 \ln GDP_{i,t-1} + \beta_1 CO2_{i,t} + \beta_2 REC_{i,t} + \gamma_1 ACCEL_{i,t} \\ & + \gamma_2 GFC_{i,t} + \gamma_3 LABFORCE_{i,t} + \mu_i \\ & + \delta_t + \varepsilon_{i,t} \end{aligned} \quad (2)$$

where $\ln GDP_{i,t-1}$ is the natural logarithm of the lagged Gross Domestic Product and an endogenous variable in the model having its parameter as α_1 ; $CO2$ and REC are the explanatory variables in this model with their parameters as β_1 and β_2 respectively; and the control variables in this model are $ACCEL$, $\ln GFC$, and $LABFORCE$, with their respective parameters as γ_1 , γ_2 and γ_3 . μ_i is the unobserved country-specific fixed effects; δ_t is the time trend and $\varepsilon_{i,t}$ is the error term. The parameters specified in Eq. (1) would only give the short-run effects of the dependent variables on the independent variable. To generate the long-run coefficients for the significant short-run parameters, the following formula is adopted:

$$\div [1 - \Phi] \quad (3)$$

where β_k is the coefficient of the k th parameter and Φ is the coefficient of the endogenous variable in the model, i.e., the lagged dependent variable included as a GMM instrument. To cover for the time variations across the panel data employed for the analysis, time dummy variables in the system GMM estimation are generated and included, after which the graph showing the behavior of the dependent variable (GDP) across the years under consideration (2008–2014) is plotted.

$$\begin{aligned} \ln GDP_{i,t} = & \alpha_1 \ln GDP_{i,t-1} + \beta_1 CO2_{i,t} + \beta_2 REC_{i,t} \\ & + \gamma_1 ACCEL_{i,t} + \gamma_2 GFC_{i,t} \\ & + \gamma_3 LABFORCE_{i,t} + \gamma_4 MOD_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \end{aligned} \quad (4)$$

where MOD is equal to $CO2 \times REC$ with its parameter estimate as γ_4 .

To align this study with the existing hypotheses in the literature linking renewable energy consumption and other energy variables to economic growth, a Granger causality test is carried out and the equations for both the test and the underlying assumption are given below:

$$\begin{aligned} \ln GDP_{i,t} = & \alpha_{0,i} + \alpha_{1,i} \ln GDP_{i,t-1} + \alpha_{2,i} \ln GDP_{i,t-2} + \beta_{1,i} REC_{i,t-1} \\ & + \beta_{2,i} REC_{i,t-2} + \varepsilon_{i,t} \end{aligned} \quad (5)$$

Table 1

Granger causality test for renewable energy consumption and economic growth.

Source: Authors' computation using Eviews 10.

Null hypothesis	Observations	F-Statistic	Probability
REC does not Granger cause $\ln GDP$	177	4.9284	0.0083
$\ln GDP$ does not Granger cause REC		0.1512	0.8598

$$\begin{aligned} REC_{i,t} = & \alpha_{0,i} + \alpha_{1,i} REC_{i,t-1} + \alpha_{2,i} REC_{i,t-2} + \beta_{1,i} \ln GDP_{i,t-1} \\ & + \beta_{2,i} \ln GDP_{i,t-2} + \varepsilon_{i,t} \end{aligned} \quad (6)$$

where t = time period and i = the cross-sectional dimensions of the panel. Note also that there are only two lags in the model. The major assumption underlying this causality is that all coefficients are the same across all cross-sections. This is expressed mathematically as thus:

$$\alpha_{0,i} = \alpha_{0,j}, \alpha_{1,i} = \alpha_{1,j}, \dots, \alpha_{1,i} = \alpha_{1,j}, \forall i,j \quad (7)$$

$$\beta_{0,i} = \beta_{0,j}, \beta_{1,i} = \beta_{1,j}, \dots, \beta_{1,i} = \beta_{1,j}, \forall i,j \quad (8)$$

4. Results

4.1. Granger causality test

To test the core hypotheses in the literature regarding the causal relationship between (renewable) energy consumption and economic growth, Table 1 presents the Granger causality test outcome for the core independent variable – renewable energy consumption (REC) and the dependent variable, economic growth presented in the natural logarithmic form ($\ln GDP$).

From Table 1, the null hypothesis of no unidirectional causality running from renewable energy consumption to economic growth is rejected since the probability value is less than 0.05. On the other hand, the null hypothesis of no Granger causality running from economic growth to renewable energy consumption is not rejected. With these outcomes, therefore, this study could conclude that there seems to be a unidirectional causality running from renewable energy consumption to economic growth, in conformity with the growth hypothesis highlighted above. This finding aligns with Nathaniel and Iheonu (2019) who found a one-way causality from both renewable and nonrenewable energy consumption but laid more emphasis on how $CO2$ emission measures correctly as an environmental variable than how it impacts economic growth. This could be a falling as their study if one argues that the ultimate beneficiary of a sustainable environment is the aggregate economy, directly or indirectly. It is, however, pertinent to point out here that, while correlation may not imply causation, the reverse may also be true.

4.2. Effects of renewable energy consumption on economic growth in Africa

In Table 2, four of the independent variables are significant, either at a 5% or 10% level of significance. The endogenous variable $\ln GDP_{-1}$ in the model, which is a lagged value of economic growth, is statistically significant at a 5% level of significance. Same with renewable energy consumption, one of the core variables of the model. Two out of the three instrumental variables included in the model are significant at 10% and 5%, and they are Access to electricity and Gross fixed capital formation in its natural logarithmic form, respectively. This result, therefore, implies that a one percent increase in renewable energy consumption relative to the total final energy consumption in Africa will lead to a 0.07% increase in economic growth in the short-run, at the 5% level of significance, on average ceteris paribus.

Table 2

Parametric Estimates for the Effect of REC and CO₂ on lnGDP, Controlling for ACCEL, lnGFC, and lnLABFORCE (t-values in parentheses). (Note: Robust options used; t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ indicate significance at 1%, 5% and 10% respectively. Estimations made using xtabond2 routine in Stata.)

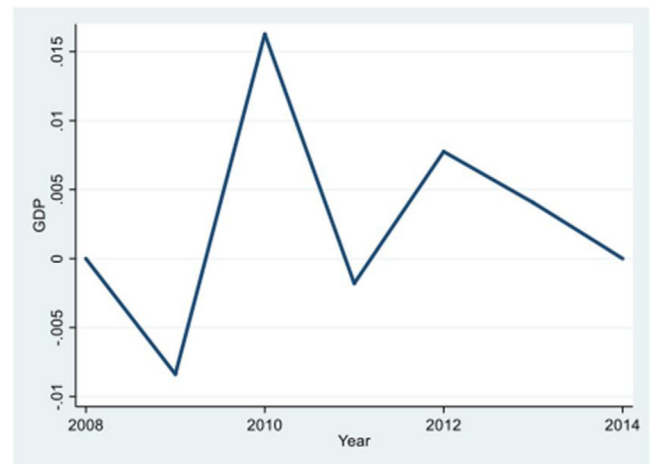
Variable	Coefficients
lnGDP_1	0.9631** (55.88)
CO ₂	1.01e-08 (0.22)
REC	0.0007** (2.27)
ACCEL	0.0006* (1.85)
lnGFC	0.0293** (2.14)
lnLABFORCE	0.0052 (1.38)
No. of Obs.	206
Time dummies	Yes
Number of instruments	31/35
F statistic	1.20e+07
GMM instrument Lag	1
AR (2)	0.363
Hansen test	0.139

This is in line with the interpretation of the log-linear model by [Gujarati \(2004\)](#). Hence, renewable energy consumption and economic growth exhibit a positive relationship since the coefficient of REC in [Table 2](#) is positive, unlike what the correlation result shows. This is justified however since co-movement of variables does not necessarily imply a relationship between the variables and vice versa and conforms with the findings of [Alper and Oguz \(2016\)](#) that renewable energy consumption has a positive and significant impact on economic growth in the short run. Their study, however, employed the asymmetric causality test approach and autoregressive distributed lag (ARDL) approach and included only Eastern European countries.

4.3. Effects of environmental sustainability on economic growth in Africa

From [Table 2](#), environmental sustainability proxied by CO₂ emission is positive but not statistically significant, hence, cannot be said to affect economic growth significantly in Africa. This is also expected since most African countries are not heavily industrialized, hence the level of emissions in comparison to other countries in other regions of the world may best be described as negligible ([Ahenkan and Osei-Kojo, 2014](#)). However, the result is in contrast with the findings of [Narayan and Narayan \(2010\)](#) that CO₂ emission has a negative and significant relationship with economic growth in 15 developing countries drawn to Africa, the Middle East, and Latin America. Their study employed the panel cointegration econometric technique, a probable justification for the difference in results. Cross-country peculiarities may also be another important factor to consider.

Apart from the individual significance of the variables used in the model and depicted by the t-statistic in parentheses, the F-statistic in [Table 2](#) also shows the overall or joint significance of all the variables employed in the analysis. The Hansen test is used to ascertain the validity of the instruments used in the model. Given that the probability of the Hansen test for the estimation above is 0.139, which is greater than 0.05, the null hypothesis that the instruments are valid cannot be rejected because there is not enough evidence to do so at the time of this research. The results in [Table 2](#) are heteroscedastic and autocorrelation consistent as

**Fig. 4.1.** Plot of GDP using the Year Dummies (2008–2014).

Source: Researcher's Plot using Stata 15.

Table 3

Long-run GMM coefficients of REC, ACCEL, and lnGFC. (Note: z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ indicate significance at 1%, 5% and 10% respectively. Estimations are done using nlcom routine in stata.)

Variable	Coefficients
REC	0.0190707** (2.61)
ACCEL	0.0152493** (2.53)
lnGFC	0.7935176** (10.38)

the robust option of the system GMM estimation technique was adopted during the model estimation using Stata 15, and also buttressed by the probability value (0.363) of the Arellano–Bond test for second-order Auto-regression in the first differences. Thus, there is no autocorrelation and heteroscedasticity in the model. Note also that, unlike the least square regression models that use the coefficient of determination (R^2) to majorly determine the goodness of fit, the system GMM uses the Hansen statistic and the ratio of several instruments and number of groups, with the rules of thumb being that the number of instruments must be less than the number of groups while the value of the Hansen statistic should be between 0.1 and 0.4 for the system GMM result to be trustworthy and the variables, a good fit. Since the result in [Table 2](#) satisfies these two conditions, this study could conclude that the results are valid.

The year dummies are generated to capture the time variations of the dependents variable (GDP) across year and country. [Fig. 4.1](#), therefore, plots the coefficients of year dummies generated from the GMM estimation to show the trend of GDP in Africa from 2008–2014.

From [Fig. 4.1](#), economic growth in Africa exhibits a very high level of fluctuation across the years under consideration and this could affect other macroeconomic indices. Since the estimates in [Table 2](#) only show the short-run impacts of the independent variables on economic growth, [Table 3](#) shows the long-run coefficients of the statistically significant variables seen in [Table 2](#).

[Table 3](#) reveals a positive relationship between renewable energy consumption and economic growth in Africa in the long run, just as it is in the short run. This finding is comparable to the argument put forward by [Bhattacharya et al. \(2016\)](#) that renewable energy consumption has a positive and significant effect on economic growth in the long run, sampling 38 renewable energy

Table 4

Parametric estimates for the effect of MOD on lnGDP, Controlling for ACCEL, lnGFC, and lnLABFORCE (t-values in parentheses). (Robust options used; t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ indicate significance at 1%, 5% and 10% respectively. Estimations are done using xtabond2 routine in Stata.)

Variable	Coefficients
lnGDP_1	0.9606** (51.01)
CO2	−2.52e−08 (−0.53)
REC	0.0006* (1.89)
ACCEL	0.0005* (1.76)
Ln GFC	0.0303** (2.08)
Ln LABFORCE	0.0056 (1.37)
MOD	2.61e−09 (1.27)
No. of Obs.	206
Time dummies	Yes
Number of instruments/Groups	32/35
F statistic	5.56e+06
GMM instrument Lag	1
R (2)	0.368
Hansen test	0.118

consuming countries and adopting both the Renewable Energy Country Attractiveness Index and time-series analyses of long-run output elasticities.

4.4. Modeling the role of environmental sustainability on the nexus between renewable energy consumption and economic growth

From Table 4, despite the inclusion of the interaction variable, MOD, renewable energy consumption remains statistically significant (at 10% now), CO2 remains statistically insignificant and the joint significance of all the independent variables is retained. Also, both the Hansen test and the Arellano–Bond autoregression test still highlight the appropriateness of the variables included in the model. Thus, environmental sustainability plays no important role in moderating the nexus between renewable energy consumption and economic growth in Africa. This finding supports the view in extant literature (Antonakakis et al., 2015) that renewable energy consumption could be analyzed concerning its direct effects or relationship with economic growth, and with the exclusion of environmental sustainability considerations

5. Discussion

Concerning the objective of the assessment of the relationship between renewable energy consumption and economic growth in Africa, this study has found strong evidence that renewable energy adoption and development will lead to an increase in economic growth in Africa. This is because its consumption has a positive relationship with gross domestic product in the continent, both in the long run and in the short run. The renewable energy consumption variable adopted in this study is measured as a percentage of total final energy consumption for African countries under consideration, hence accounts for the exclusive contribution of renewable energy use to the economy and aptly describes the interactions between renewable energy and nonrenewable energy in a country's energy portfolio. The positive and significant relationship between this variable (REC) and GDP (in its natural logarithmic form), therefore, supports the claim of this

study found. The finding is also similar to that of Eggoh et al. (2011), and Ahmed and Shimada (2019) who found a significant long-run relationship between renewable energy consumption and economic growth, not just in Africa, but also in South Asia and other Asian countries. On the contrary, however, Ergun et al. (2019) have found a negative relationship between gross domestic product per capita and renewable energy adoption. The slight contradiction is justified by them as being possible when biomass comprises the bulk of renewables adopted and consumed, as is the case in many African countries. Further justifications for the differences in findings include the fact that the study by Ergun et al. (2019) adopted the per capita GDP, a micro-level variable different from the GDP employed for this study. One may argue that the effects of renewable or nonrenewable energy consumption on personal income may be quite distinct from that on national income, thus further validating the discrepancies in findings among energy researchers. Also, while Ergun et al. (2019) adopted the random effect generalized least squares regression estimation technique, this study employs the system generalized method of moments (GMM) estimation technique, which allows for a very flexible identification of estimates and requires minimal assumptions about the data generating process (DGP). Thus, the distribution of the error terms in the model of the DGP in this study needs not to be specified.

Another important finding of this study, which is in line with the second objective – analyzing the relationship between environmental sustainability and economic growth in Africa – is that the effect of CO2 emissions in Africa's economy is still insignificant and hence, promoting environmental sustainability through a reduction of emission is not a priority in Africa's quest for all-inclusive growth and development. This finding is somewhat similar to the study by Howes et al. (2016) who found that despite efforts aimed at increasing environmental sustainability through the enactment of environmental laws, regional programs, etc., only a little or no improvement has been felt in that regard for the African region, signaling that it may not be the most important economic issue for the continent yet. Denny and Marquat-Pyatt (2018) found that demographic features can affect environmental sustainability tremendously, depending on the region under consideration. From the finding of this study, even Africa's demography appears to be doing very little in terms of environmental sustainability. Besides, there are emerging carbon technologies that can enable countries to efficiently combine both the traditional and renewable energy resources in the short run until they are fully mature to phase out fossil fuels and transit completely to renewable energy utilization. Most African economies are still nascent, with largely fossil reserves. Hence, this combination of renewables and nonrenewables, and the gradual reduction and containment of carbon emissions seem like a way to go in the short run. This submission could apply to other developing countries in Asia and Latin America, whose growth convergence may take longer if they solely rely on renewable energy for economic activities at the early stage.

This study further finds that CO2 emission plays no significant role as a nexus factor between renewable energy consumption and economic growth in Africa. This evidence supports the third objective, aimed at investigating the moderating role of environmental sustainability on the nexus between renewable energy consumption and economic growth in Africa. The finding is slightly in contrast with the study of Ahmed and Shimada (2019) who strictly focused on the nexus between renewable energy consumption and economic growth using causality tests and without including any moderating variable. They found a bi-directional causality between them, hence, aligning with the feedback hypothesis. This study is in line with the growth hypothesis. Environmental considerations have probably not received

enough attention among the biggest energy players in many African countries. Some top energy companies use a reduction in their corporate social responsibility and environmental protection activities as a market entry strategy into the most underdeveloped and vulnerable countries in Africa. Given the weak institutional framework in the host country, they are rarely held accountable. This lends some justifications to why environmental sustainability concerns do not alter the relationship between renewable energy consumption and economic growth in Africa. It also calls for a rethink, perhaps.

6. Conclusion and recommendations

The global attention to renewable energy consumption has increased in recent years, mainly due to the depleting fossil fuels, environmental degradation, and the argument that it can improve the standard of living in developing countries. However, its nexus with environmental sustainability and its combined effects on economic growth has not been well researched. Thus, this paper investigates the effects of renewable energy consumption and environmental sustainability in Africa. The study involves thirty-seven African countries selected based on their nominal GDP, with data gathered from the World Development Indicators (WDI) database of the World Bank (WDI, 2018) within a time scope of 2008 and 2014, limited due to data availability. Using a panel data analysis and employing the system GMM estimation technique, the study finds that (i) renewable energy consumption and economic growth have a positive relationship in Africa, both in the short-run and the long run (ii) no significant relationship exists between environmental sustainability variable, CO₂, and economic growth in Africa; and (iii) environmental sustainability, as a moderating variable, does not cause any major change in the nexus between renewable energy consumption and economic growth in Africa.

The study has touched on aspects of the dynamics of Africa's economy and a thorough understanding of these dynamics will hasten the attainment of both the UN SDGs by 2030 and Agenda 2063. As a policy implication, African governments could borrow some lessons from this study to implement economy and environment-oriented energy policy decisions and ultimately improve the living standard of the citizens. Synergy in the adoption of both renewable and nonrenewable energy is needed in Africa since most of the economies are still nascent and would take a while to completely phase off the traditional energy. Finally, large energy companies in Africa could improve in the sustainability considerations and corporate social responsibilities in their activities to enhance more environmental sustainability in the content.

7. Limitations of study

The field of renewable energy consumption is still open for further research, especially in the context of African society, thus, there seems to be an inherent difficulty in gathering data on renewable energy consumption and other environmental sustainability considerations. This was a major limitation for this study as it could only assess a balanced panel up until 2014, of the 37 African countries that were studied. Some earlier studies (Ergun et al., 2019) have also reported this dearth of data as a barrier to more accurate energy research in the African context; This implies that there is a need for more research in the future on the dynamics of renewable energy consumption and environmental sustainability about economic growth in Africa, using more recent datasets. It will be of interest to energy scholars within and outside Africa to contribute more research on how renewable energy investments for low carbon growth in African economies could be increased to enhance environmental protection and overall sustainability.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Ahenkan, A., Osei-Kojo, A., 2014. Achieving sustainable development in Africa: Progress, challenges, and prospects. *Int. J. Dev. Sustain.* 3 (1), 162–176.
- Ahmed, M.M., Shimada, K., 2019. The effect of renewable energy consumption on sustainable economic development: Evidence from emerging and developing economies. *Energies* 12 (2954), 1–15. <http://dx.doi.org/10.3390/en12152954>.
- Alper, A., Oguz, O., 2016. The role of renewable energy consumption in economic growth: Evidence from asymmetric causality. *Renew. Sustain. Energy Rev.* 60, 953–959.
- Antonakakis, N., Chatziantoniou, I., Filis, G., 2015. Energy Consumption, CO₂ Emissions, and Economic Growth: A Moral Dilemma. MPRA Paper No. 67422, <https://mpra.ub.uni-muenchen.de/67422/>.
- Anyanwu, J.C., 2014. Factors affecting economic growth in Africa: Are there any lessons from China? *Afr. Dev. Rev.* 26 (3), 468–493.
- Armeanu, D.S., Vintila, G., Gherghina, S.C., 2017. Does renewable energy drive sustainable economic growth? Multivariate panel data evidence for EU-28 countries. *Energies* 10 (381), <http://dx.doi.org/10.3390/en10030381>.
- Asongu, S.A., 2017. Comparative Sustainable Development in Sub-Saharan Africa. MPRA Paper No. 85487, <https://mpra.ub.uni-muenchen.de/85487/>.
- Asongu, S.A., Roux, S., Biekpe, N., 2018. Enhancing ICT for environmental sustainability in Sub-Saharan Africa. *Technol. Forecast. Soc. Change* 127, 209–216. <http://dx.doi.org/10.1016/j.techfore.2017.09.022>.
- Aspergis, N., Danuletiu, D.C., 2014. Renewable energy and economic growth: Evidence from the sign of panel long-run causality. *Int. J. Energy Econ. Policy* 4 (4), 578–587.
- Aspergis, N., Payne, J.E., 2009. Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model. *Energy Econ.* 31, 211–216. <http://dx.doi.org/10.1016/j.eneco.2008.09.002>.
- Bartniczak, B., Raszkowski, A., 2018. Sustainable development in African countries: An indicator-based approach and recommendations for the future. *Sustainability* 11 (22), <http://dx.doi.org/10.3390/su11010022>.
- Bhattacharya, M., Paramati, S.R., Ozturk, I., Bhattacharya, S., 2016. The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Appl. Energy* 162, 733–741.
- Bildirici, M., Özkarsoy, F., 2018. An analysis of biomass consumption and economic growth in transition countries. *Econ. Res.-Ekon. Istraž.* 31 (1), 386–405.
- Boulding, K.E., 1966. The economics of the coming spaceship earth. In: Jarrett, H. (Ed.), *Environmental Quality in a Growing Economy*. Johns Hopkins University Press, Baltimore.
- Bozkurt, C., Destek, M.A., 2015. Renewable energy and sustainable development nexus in selected OECD countries. *Int. J. Energy Econ. Policy* 5 (2), 509–514.
- Brodny, J., Tutak, M., 2020. Analyzing similarities between the European Union countries in terms of the structure and volume of energy production from renewable energy sources. *Energies* 13 (4), 913.
- Brouwer, A.S., van den Broek, M., Zappa, W., Turkenburg, W.C., Faaij, A., 2016. Least-cost options for integrating intermittent renewables in low-carbon power systems. *Appl. Energy* 161, 48–74. <http://dx.doi.org/10.1016/j.apenergy.2015.09.090>.
- Chen, S.T., Kuo, H.I., Chen, C.C., 2007. The relationship between GDP and electricity consumption in 10 Asian countries. *Energy Policy* 35, 2611–2621. <http://dx.doi.org/10.1016/j.enpol.2006.10.001>.
- Chukwu, V.E., 2020. Potentials, drivers and barriers to green economy transition: Implications for africa. *Adv. J. Plant Biol.* 1 (1), 7–17. <http://dx.doi.org/10.31248/AJPB2020.006>.
- Denny, R.C.H., Marquat-Pyatt, S.T., 2018. Environmental sustainability in Africa: What drives the ecological footprint over time? *Sociol. Dev.* 4 (1), 119–144. <http://dx.doi.org/10.1525/sod.2018.4.1.119>.
- Dogan, E., Sebr, M., Turkekul, B., 2016. Exploring the relationship between agricultural electricity consumption and output: New evidence from Turkish regional data. *Energy Policy* 95, 370–377. <http://dx.doi.org/10.1016/j.enpol.2016.05.018>.
- Dragulanescu, I.V., Dragulanescu, N., 2013. Some theories of environmental sustainability. *Rom. Stat. Rev.* (12), 14–23.

- Eggoh, J.C., Bangake, C., Rault, C., 2011. Energy Consumption and Economic Growth Revisited in African Countries. CESIFO Working Paper No. 3590, Category 10: Energy and Climate Economics, 2011.
- Ergun, S.J., Owusu, P.A., Rivas, M.F., 2019. Determinants of renewable energy consumption in Africa. *Environ. Sci. Pollut. Res.* <http://dx.doi.org/10.1007/s11356-019-04567-7>.
- Gujarati, D.N., 2004. *Basic Econometrics*, fourth ed. McGraw-Hill Companies.
- Harrison, K., Adams, T., 2017. An evidence review: How affordable is off-grid energy access in Africa?
- Howes, M., Wortley, L., Potts, R., Dedekorkut-Howes, A., Serrao-Neumann, S., Davidson, J., Smith, T., Nunn, P., 2016. Environmental sustainability: a case of policy implementation failure? *Sustainability* 9 (165), <http://dx.doi.org/10.3390/su9020165>.
- Inglese-Lotz, R., 2016. The impact of renewable energy consumption to economic growth: A panel data application. *Energy Econ.* 53, 58–63. <http://dx.doi.org/10.1016/j.eneco.2015.01.003>.
- ISPI, 2016. Environmental and Social Sustainability in Africa. ISPI Background Paper No. 2.
- Jamel, L., Derbali, A., 2016. Do energy consumption and economic growth lead to environmental degradation? Evidence from Asian economies. *Cogent Econ. Finance* 4.
- Le, T., Chang, Y., Park, D., 2020. Renewable and nonrenewable energy consumption, economic growth, and emissions: International evidence. *Energy J.* 41 (2), 73–92.
- Lee, J.W., 2019. Long-run dynamics of renewable energy consumption on carbon emissions and economic growth in the European Union. *Int. J. Sustain. Dev. World Ecol.* 26 (1), 69–78. <http://dx.doi.org/10.1080/13504509.2018.1492998>.
- Maji, I.K., Sulaiman, C., Abdul-Rahim, A.S., 2019. Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa. *Energy Rep.* 5, 384–392. <http://dx.doi.org/10.1016/j.egy.2019.03.005>.
- Marinaş, M.C., Dinu, M., Socol, A.G., Socol, C., 2018. Renewable energy consumption and economic growth. Causality relationship in central and eastern European countries. *PLOS ONE* 13 (10), 1–29. <http://dx.doi.org/10.1371/journal.pone.0202951>.
- Mohammadi, H., Ram, R., 2017. Convergence in energy consumption per capita across the US states, 1970–2013: An exploration through selected parametric and non-parametric methods. *Energy Econ.* 62, 404–410. <http://dx.doi.org/10.1016/j.eneco.2016.07.002>.
- Moral-Benito, E., 2009. Determinants of Economic Growth: A Bayesian Panel Data Approach. Working Paper 4830, World Bank Policy Research.
- Narayan, P.K., Narayan, S., 2010. Carbon dioxide emissions and economic growth: Panel data evidence from developing countries. *Energy Policy* 38 (1), 661–666.
- Nathaniel, S.P., Iheonu, C.O., 2019. Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. *Sci. Total Environ.* 679, 337–345.
- Ndambiri, H.K., Ritho, C., Ng'ang'a, S.J., Kubowon, P.C., Mairura, F.C., Nyangweso, P.M., Muiruri, E.M., Cherotwo, F.H., 2012. Determinants of economic growth in Sub-Saharan Africa: a panel data approach. *Int. J. Econ. Manage. Sci.* 2 (2), 18–24.
- Neuhaus, L., 2016. Examining Renewable Energy Consumption- Economic Growth Nexus in Sub-Saharan African Countries (Honors Program Theses). p. 241, <https://scholarworks.uni.edu/hpt/241>.
- Nguyen, K.H., Kakinaka, M., 2019. Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renew. Energy* 132, 1049–1057.
- Ntamos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., Batzios, A., Katsarou, A., 2018. Renewable energy and economic growth: Evidence from European countries. *Sustainability* 10 (2626), <http://dx.doi.org/10.3390/su10082626>.
- Nyiwiul, L., 2018. Income, environmental considerations, and sustainable energy consumption in Africa. *Int. J. Green Energy* <http://dx.doi.org/10.1080/15435075.2018.1439037>.
- Ocal, O., Aslan, A., 2013. Renewable energy consumption – economic growth nexus in Turkey. *Renew. Sustain. Energy Rev.* 28, 494–499. <http://dx.doi.org/10.1016/j.rser.2013.08.036>.
- Omri, A., Euch, J., Hasaballah, A.H., Al-Tit, A., 2019. Determinants of environmental sustainability: Evidence from Saudi Arabia. *Sci. Environ.* 657, 1592–1601. <http://dx.doi.org/10.1016/j.scitotenv.2018.12.111>.
- Oyebanjo, O., 2017. Determinants of Economic Growth in Sub-Saharan Africa: Decomposition of Exports and Imports. A Thesis Presented to the Graduate School of Business, University of Cape Town, in Partial Fulfilment of the Requirements for the Master of Commerce in Development Finance Degree.
- Ozturk, I., 2010. A literature survey on energy-growth nexus. *Energy Policy* 38, 340–349. <http://dx.doi.org/10.1016/j.enpol.2009.09.024>.
- Said, K., Hammami, S., 2015. The impact of CO2 emission and economic growth on energy consumption in 58 countries. *Energy Rep.* 1 (62–70), <http://dx.doi.org/10.1016/j.egy.2015.01.003>.
- Samimi, A.J., Ghaderi, S., Ahmadpour, M., 2011. Environmental sustainability and economic growth: Evidence from some developing countries. *Adv. Environ. Biol.* 5 (5), 961–966.
- Sawin, J.L., Sverrisson, F., Leidreiter, A., 2016. Renewable Energy and Sustainable Development: Accounting for Impacts on the Path to 100% RE. World Future Council.
- Singh, N., Nyuur, R., Richmond, B., 2019. Renewable energy development as a driver of economic growth: Evidence from multivariate panel data analysis. *Sustainability* 11 (2418), <http://dx.doi.org/10.3390/su1108241>.
- Squalli, J., 2007. Electricity consumption and economic growth: Bounds and causality analyses of OPEC members. *Energy Econ.* 29, 1192–1205. <http://dx.doi.org/10.1016/j.eneco.2006.10.001>.
- Tugcu, C.T., Ozturk, I., Aslan, A., 2012. Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. *Energy Econ.* 34, 1942–1950. <http://dx.doi.org/10.1016/j.eneco.2012.08.021>.
- Tutak, M., Brodny, J., Siwiec, D., Ulewicz, R., Bindzár, P., 2020. Studying the level of sustainable energy development of the European union countries and their similarity based on the economic and demographic potential. *Energies* 13 (24), 6643.
- UNECA, 2014. Managing land-based resources for sustainable development. sustainable development report on Africa.
- United Nations, 2013. Sustainable Development Challenges. Department of Economic and Social Affairs.
- WDI, 2018. World development indicators. <https://databank.worldbank.org/source/world-development-indicators>.